AMERICAN BLACK BEAR ECOLOGY IN THE OKLAHOMA OZARKS: HOME RANGE ESTIMATION, FRAGMENTATION ANALYSIS, AND RESOURCE SELECTION

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Abstract: Black bears (*Ursus americanus*) were extirpated from Oklahoma in the late 19th century but have since recolonized eastern portions of the state after successful translocations in Arkansas. Within the last two decades, a population of black bears was detected in the Oklahoma Ozark region, prompting multiple demographic studies to determine population size, growth rate and genetic makeup. To understand how black bears were recolonizing the human-dominated landscape, we investigated individual home ranges, effects of fragmentation on male and female black bears and resource selection at two scales.

Between 2011 – 2016, GPS collar spatial data was collected for 23 individuals (10M, 13F). Average kernel density estimated home ranges were calculated on a seasonal scale for both males and females using ArcGIS 10.2 and Geospatial Modeling Environment. Based on 72 female home ranges (38 summer, 34 autumn) and 17 male home ranges (7 summer, 10 autumn), we determined that female home ranges were significantly smaller than male home ranges. Fragmentation analysis was conducted in FRAGSTATS v.4.2.1 on the landscape scale, using the edge density and contagion metrics. We found that females are sensitive to fragmentation whereas males are not. These results suggested that anthropogenic fragmentation may limit suitable areas for female home ranges, and therefore limit growth of this population.

Resource selection functions were calculated using R v.3.4.3 as generalized linear mixed models (GLMMs). Resource selection was calculated on the study area and home range scales, to understand detailed differences in selection. Black bears across seasons and scales selected riparian forest and moist oak forest land cover types while mostly selecting against indicators of human activity, such as the pasture/prairie and anthropogenic land cover types as well as roads and areas of high human population density. Black bears did not differ in selection by sex, although females were found to be further from roads than males, on average. Thus, areas and features characterized as human-altered may negatively impact black bear recolonization, especially the females. Further expansion of the species' distribution could be slowed or halted if female black bear movement is significantly impeded by anthropogenic disturbance in the region.

TABLE OF CONTENTS

LIST OF TABLES

Table Page

CHAPTER 2

CHAPTER 3

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The impact of a growing human population on species in the mammalian Order Carnivora is a major force in shaping of various species' ecology (Beckman and Berger 2003, Cardillo et al. 2004). As human development expands, human encroachment leads to a scarcity of large tracts of continuous land. Habitat fragmentation especially challenges large carnivores such as mountain lions (*Puma concolor*) and grizzly bears (*Ursus arctos*), due to their need for large home ranges (Proctor et al. 2002, Riley et al. 2014). The effects of fragmentation vary substantially among large carnivore species, but often manifest in altered patterns of habitat selection, vigilance, daily activities and foraging that can lead to severe population declines (Clark et al. 2002, Cardillo et al. 2005, Chapron et al. 2014, Johnson et al. 2015).

Successful recolonization of a carnivore species in a significantly modified part of their historical range is a rare occurrence, and research in this field is relatively lacking (Onorato and Hellgren 2001). However, natural and human-assisted recolonization efforts are succeeding at an increased rate (Chapron et al. 2014). Examples of successful carnivore recolonizations can be found throughout the carnivore taxon, including gray wolves (*Canis lupus*), mountain lions, brown bears, and Eurasian lynx (*Lynx lynx*), across a spectrum of land cover types (Berger et al. 2001, Chapron et al. 2014, Gilbert et al. 2016). Recolonization of a carnivore species presents a variety of unique management challenges (Onorato and Hellgren 2001, Clark et al. 2002), and effective wildlife management practices require in-depth knowledge of the impact of human development on each species' ecology (Woodroffe 2000, Linnell et al. 2001). Ecological assessments of the species in question enables the development of policy based on more accurate resource selection information, which is essential for conservation (Manly et al. 2002).

Based on the theory of ideal free-distribution, a species will choose to live in a certain area according to interspecific and intraspecific competition as well as habitat productivity and spatial arrangement of the available resources (Fretwell 1972). Animals also are expected to use habitat with a tradeoff between minimizing exposure to risk while maximizing access to resources (Brown 1987). However, the introduction of fragmented habitat and anthropogenic sources of food and cover might alter the theoretically expected behavior patterns (Frid and Dill 2002). Carnivore species such as the American black bear (*Ursus americanus*) may become habituated to humans and alter their behavior to exploit these food and cover resources, especially during times of hyperphagia (the period of increased foraging prior to hibernation), and resource scarcity (Johnson et al. 2015), or if the perceived disturbance from humans is relatively low (Beckmann and Berger 2003). Behavioral changes such as this one follow the risk-disturbance hypothesis, which states that the trade-off between the perceived benefits and risks (including human-related presence or objects) associated with acquiring key resources will dictate the individual's behavior (Frid and Dill 2002). Furthermore, animals that are exposed to disturbance stimuli, such as human development but do not have suitable alternative habitats are forced to live in and adapt to low-quality habitat (Gill et al. 2001). Because species such as the black bear reintegrate into a habitat already characterized by anthropogenic disturbance stimuli and human-altered resources, land cover selection may not necessarily match ideal free-distribution theory (Gill et al. 2001). Therefore, a different view of local habitat productivity and selection must be established.

Black bear habitat in the eastern United States changes by location, although it can generally be summarized by a few simple characteristics, because the black bear is the most widely distributed of all ursids in North America (Pelton 2003). Primarily, black bear habitat will contain a thick understory that provides herbaceous hard and soft mast and cover for denning (Lyons et al. 2003, Sadeghpour and Ginnett 2011, Karelus et al. 2016). It is well documented that black bears will naturally eat a highly varied diet centered on mast species (Payne et al. 1998), but will alter their eating habits when anthropogenic food sources are available (Beckmann and Berger 2003; Ditmer et al. 2015; Hopkins et al. 2014; Artz, 2016). Furthermore, a thick overstory for shade, food, and cover is an integral part of typical black bear habitat (Sadeghpour and Ginnett 2011). Black bears will often avoid higher-trafficked roads (Fecske et al. 2002) while ignoring or even preferring to travel on lower-trafficked roads (Sadeghpour and Ginnett 2011; Lyda et al. 2007). However, use or avoidance of roads is dependent on location (Reynolds-Hogland and Mitchell 2007), time of year, and local management policies, such as hunting (Stillfried et al. 2015). Additionally, black bears are known to avoid urban areas and agricultural land, most likely due to lack of food sources and perceived danger (Karelus et al. 2016). However, selection against urban areas and agriculture land is not ubiquitous, as many individual black bears will take advantage of resources found in human development areas including cities, ranches, campgrounds and farms (Ditmer et al. 2015; Johnson et al. 2015; Hopkins et al. 2014; McFadden-Hiller et al. 2016).

Recolonizing black bears inhabiting fragmented habitat, less productive habitat, or a combination of the two may require larger home ranges than black bears inhabiting all-natural habitats (Moyer et al. 2007). Studies of space use by species, in addition to resource selection, will improve our understanding of how recolonizing species are inserting themselves into a human-dominated landscape, and how that relates to human-wildlife conflict.

Black bears were extirpated from a sizeable part of their distribution in the late 19th century (Smith and Clark 1994). However, favorable management plans have more recently allowed black bears to recolonize many parts of its historical distribution throughout North America, both through translocation and natural recolonization. The Interior Highlands of Oklahoma, Missouri, Kansas, and Arkansas, which was once heavily occupied by bears, supported only a small, remnant population of black bears in Arkansas until 1958 when the Arkansas Game and Fish Commission began black bear reintroductions in Arkansas. By 1968, 254 bears had been translocated, and they spread throughout Arkansas (Smith and Clark 1994). Eventually, black bears naturally moved into Oklahoma, following the Ouachita (late 1990's) and Ozark (early 2000's) mountain ranges to create two geographically distinct populations (Lyda et al. 2007, Puckett et al. 2014, Yaklin 2017).

Recent studies on the black bear population in the Ouachita mountain range in southeastern Oklahoma indicated that the population was well established and growing slowly, despite legislation that allowed hunting (Pfander 2016). Population growth metrics such as fecundity and litter size were similar to metrics typical of an established black bear population (Pfander 2016). In comparison, the black bears of the Ozark Mountains in east-central Oklahoma have more recently begun the recolonization process, and based on recent research, the population is not yet self-sustaining (Lyda et al. 2016). Mark-recapture data revealed a male-dominated sex ratio, and fecundity rates were not yet high enough to facilitate substantial population growth (Lyda et al. 2016, Artz 2016). As of 2016, approximately 80 black bears had recolonized the Oklahoma Ozark region (Lyda et al. 2016). The habitat available to black bears in the Ouachita Mountains differs considerably from sites in the Oklahoma Ozark study area (Lyda et al. 2016). The Ouachita National Forest makes up much of the black bear range in the Ouachita Mountains, while the Oklahoma Ozark region consists of potentially suitable habitat patches fragmented by roads, towns, and small, private land holdings. Recolonization of the Oklahoma Ozark region by black bears is unlikely to occur in the same manner, or as rapidly, as the population in the Ouachita Mountains because of this fragmentation (Clark et al. 2002).

To effectively manage the Oklahoma Ozark population of black bears, the habitat potential of the region as well as the impact of habitat fragmentation on this population must be understood (Johnson 1980, Hostetler et al. 2008). As black bears recolonize the Oklahoma Ozark region, the rate of human-wildlife conflict will potentially increase (Johnson et al. 2015, Baruch-Mordo et al. 2008, McFadden-Hiller et al. 2016). Negative attitudes towards black bears caused by human-wildlife conflict could become a major issue for the recolonizing black bear population, which could lead to the failure of management and conservation efforts (Onorato and Hellgren 2001, Chavez et al. 2005). Using GPS collar spatial data from 2011 – 2016, I assessed the effects of habitat fragmentation on black bear behavior in the Oklahoma Ozarks by analyzing resource selection and home range characteristics of the population and comparing that population to others living in the southeastern United States (Beckman and Berger 2003, Moyer et al. 2007). With this study, I was able to provide a better understanding as to how black bears recolonize a human-altered landscape. This research can be used to direct future management and conservation practices for the black bear population in the Oklahoma Ozarks, and can provide a data-driven model for predicting black bear recolonization.

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CHAPTER II

HOME RANGE AND HABITAT FRAGMENTATION ANALYSIS OF AMERICAN BLACK BEARS IN THE OKLAHOMA OZARK REGION

Introduction

Understanding how large carnivores respond to human disturbance is essential to future conservation efforts on an international scale. The distributions of carnivore species such as mountain lions (*Puma concolor*), brown bears (*Ursus arctos*) and wolves (*Canis lupus*) are increasingly overlapping with human-dominated landscapes (Linnell et al. 2001, Benson et al. 2016), thereby creating the need for studies on how animal populations adapt to this new and altered environment. In many cases, large carnivore species have been extirpated from their historic ranges on an international scale due to anthropogenic factors such as human development and habitat loss (Cardillo et al. 2005). However, favorable management policy can facilitate the creation of a sustainable human-wildlife interface that promotes large carnivore persistence while safeguarding against human-wildlife conflict (Linnell et al. 2001, Chapron et al. 2014).

The American black bear (*Ursus americanus*) has been extirpated from much of its historical distribution due to overhunting and habitat loss, although regulations and successful reintroduction programs are allowing the species to regain a foothold in parts of the eastern United States (Smith and Clark 1994, Hiller et al. 2015, Karelus et al. 2016). Large-scale translocations have led to the recolonization of areas once densely populated by black bears (Clark et al. 2002). In the early 2000s, descendants of black bears originally translocated into the Ozark mountains of Arkansas began naturally recolonizing the east-central part of Oklahoma known as the Oklahoma Ozark region (Artz 2016). Recolonization by large carnivores in general is rare (Hellgren et al. 2005), and the creation of a new human-wildland interface can create new sources of conflict (Nellemann et al. 2007). Recolonizing black bears moving into the Oklahoma Ozarks region are encountering a landscape fragmented by anthropogenic features such as towns, cities, roads, and agricultural land. Determining how black bears interact with these features is a crucial step in understanding this species' ability to recolonize a human-dominated landscape such as the Oklahoma Ozark region.

Growing populations of black bears and other large carnivore species require large amounts of space with access to sufficient amounts of food (Pelton 2003, Chapron et al. 2014). Black bears are known to be highly adaptable with respect to their habitat requirements, although a population will not persist if the essentials are not available (Pelton 2003). Variation of home range size is affected by multiple factors, notably resource availability and habitat fragmentation (Beckmann and Berger 2003, Moyer et al. 2007). As resources such as food increase in availability, home ranges typically decrease in size and vice versa (Oli et al. 2002, Riley et al. 2003, Mitchell and Powell 2008). Additionally, a region's essential resources can only support a certain number of individuals. By calculating the degree of home range overlap on a seasonal scale, it is possible to quantify the amount of overlap tolerated by individuals in regard to space and resource use in a given area (Ward and Krebs 1985, Poole 1995). Mean home range size averages and the percent of home range overlap can help predict black bear recolonization in the Oklahoma Ozarks.

Habitat fragmentation, or the division of contiguous land into smaller, more complex habitat patches, is often caused by human expansion into natural areas (McGarigal et al. 2012). As contiguous land becomes patchy, animals that cannot live within fragmented landscapes suffer. Some animals actually benefit from a human-fragmented habitat. Opossums (*Didelphis virginianus*) and gray foxes (*Urocyon cinereoargenteus*) existed in higher relative abundance as habitat fragmentation increased (Crooks 2002). However, larger carnivores such as bobcats (*Lynx rufus*) and coyotes (*Canis latrans*) are negatively affected by human-altered, fragmented habitat (Riley et al. 2003). Black bears in Florida had increased home range sizes in response to anthropogenic fragmentation, suggesting that non-natural areas are less suitable for bears than natural areas such as riparian forest (Karelus et al. 2016). However, black bears in the Elk Mountain Range of Colorado depend heavily on human food sources associated with anthropogenic fragmentation (Johnson et al. 2015). Depending on the black bear population's sensitivity toward fragmentation, connectivity between habitat patches can become strained as fragmentation increases, possibly limiting the recolonization potential of the population (Dixon et al. 2006).

This study aimed to determine the relationship between black bears and fragmentation in the Oklahoma Ozarks, and how it might affect further recolonization of the area. Understanding how males and females differed in their space use in relation to home range size, overlap, and sensitivity to fragmentation is especially important to help determine whether a recolonizing black bear population has the space required to continue expanding the edge of their current distribution. As black bears continue to recolonize human-dominated landscapes, this information will facilitate future policy, conservation and management planning throughout the species' distribution.

Methods

Study Area

The study area contains parts of seven counties in east-central Oklahoma: Cherokee, Sequoyah, Adair, Mayes, Delaware, Wagoner and Muskogee. The majority of the land is privately owned, but some patches of public land are included in the study area, notably the 59.6 km^2 Cookson Wildlife Management Area. The western edge of the study area is characterized by numerous natural areas with high volumes of human recreation, such as Tenkiller State Park and Snake Creek Cove Campground (U.S. Army Corps of Engineers). The study area consists primarily of oak (*Quercus* spp.)-hickory forest (*Carya* spp.), with short-leaf pine (*Pinus echinata*) in small amounts at higher elevations. Soft mast species in the area include seasonal fruiting species such as blackberries (*Rubus* spp.), black cherries (*Prunus serotine*), and persimmons (*Diospyros virginana*). Anthropogenic food sources, such as corn feeders for deer and beehives, are also commonly found throughout much of the study area and are known to supplement the diet of some individuals in the Oklahoma Ozark black bear population (Artz 2016). The eastern part of the study area contains the Ozark Mountains, which cross from Arkansas into Oklahoma. Land use by humans within the study area is largely recreation-related, with a focus on hunting. Prairie and pastureland substantially outnumber row crop acreage, and can be found in varying patch sizes throughout the region. The region is latticed with numerous small and medium-sized roads and trails, as well as a few large highways and railroads. Human population centers within the study area include towns and small cities with populations ranging from approximately 4,000 to 17,000 people.

Capture and Handling

Black bears were live-trapped in 2011 – 2016 with full enclosure barrel traps and culvert traps baited with pastries, sardines, and feed corn. Live trapping teams maintained trap lines of varying number of traps within the study area for each trapping season. Trap lines were located in areas of known black bear occurrence and were based on land owner permissions, camera trap data (Lyda et al. 2016), and a hair-snare study on this population conducted in 2014 – 2016 (Artz 2016). Captured bears were sedated with a 2:1 mixture of Telazol and Xylazine at a dosage rate of 4.8 – 7.0 mg/kg (Clark and Smith 1994), administered intramuscularly with a pole syringe (Clark 1991). We marked captured bears with plastic ear tags and a lip tattoo with corresponding, unique identifying numbers. Tissues removed to attach ear tags were preserved for future genetic analysis. We gave captured bears an injection of 2-4 mg/kg of Carprofen for pain management, and collected a vestigial first upper premolar for aging, as well as a hair sample for DNA analysis. We placed Advanced Telemetry Systems G2110E Iridium GPS location collars (Advanced Telemetry Systems [ATS], Asanti, MN) on select bears throughout all capture seasons to collect data at variable schedules. Trapping continued throughout the length of the project to catch new individuals or replace and refurbish collars that required maintenance. All animal handling procedures were approved by Oklahoma State University Institutional Animal Care and Use Committee (IACUC) Protocol #AG-13-6.

Home range analysis

Spatial data from 23 radio-collared individuals (10M, 13F) was collected in 2011 – 2016. Data for each individual was divided into three seasons based on local food availability and bear behavior in the Oklahoma Ozarks: summer (May – August), autumn (September – December) and winter (January – April, Lyda et al. 2007). An individual's seasonal dataset was excluded from the remainder of the study if it contained fewer than 50 locations (Yaklin 2017). Datasets were rarified to include a maximum of two points per day per individual, separated by ≥ 12 hours, to reduce spatial and temporal autocorrelation between locations (Swihart and Slade 1985). Using the kernel density estimation (KDE) method, 95% and 50% isopleth home ranges were created for each bear's seasonal data with commands *kde* and *isopleth* in Geospatial Modeling Environment (GME; Beyer 2012). Cell size was set to 30 m to account for any error created by the GPS collars (Pfander 2016), and the Least Squares Cross Validation (LSCV) method was used to calculate the smoothing parameter (Seaman and Powell 1996). Home range estimates greater or less than 1.5 times the interquartile range were considered outliers and excluded from the remainder of the study (Dovoedo and Chakraborti 2014). This process removed all dispersing males' home ranges from the analysis, leaving only 'permanent' male home ranges.

Mean home range estimates were calculated for females and males separately, because sex can significantly affect average home range area (Dahle and Swenson 2003). The distribution of outputs was tested for normality with the Shapiro-Wilk normality test (Shapiro and Wilk 1965). Mean home range estimates were calculated for both males and females on a seasonal timescale. Availability of data did not allow for annual home range estimates. Comparisons between males and females were calculated using the Mann-Whitney *U*-test for nonparametric data (Mann and Whitney 1947) on both timescales. Unless otherwise specified, future references to a home range can be assumed as a 95% isopleth estimate.

Percent home-range overlap (PHO; Macdonald et al. 1980, Poole 1995, Oli et al. 2002) is a 2-dimensional static index between an individual and the rest of the population. This statistic does not look at the effects of interactions between individuals, as there is no fine-grain temporal aspect involved in the creation of KDE home ranges. PHO was analyzed for each individual, calculating the percentage of home range overlap of the subject's home range area for each instance of overlap per season. The PHO values were then averaged for each individual and then by sex. Means were also calculated by age-class, sub-adult (2-4 years old) and adult (4+ years old). There were no individuals below the age of 2 with home range data.

Precise study area boundaries were calculated by creating a minimum convex polygon (MCP) of all data points used in the final KDE estimation (Hiller et al. 2015) with command *genmcp* in GME (Figure 2.1, Beyer 2012).

Fragmentation Analysis

Fragmentation was analyzed in FRAGSTATS 4.2.1 (McGarigal et al. 2012), with metrics edge density (ED) and contagion (CONTAG). ED is the total length of edge within the landscape, divided by the total landscape's area ($\mathrm{ED} = \frac{\mathrm{E}}{\mathrm{A}}$). As ED increases, the amount of edge between land cover types within the landscape increases, thus signifying a higher degree of fragmentation within the landscape. With ED, it is possible to compare landscapes of different sizes, providing more accuracy than total edge when comparing between home ranges (McGarigal et al. 2012). CONTAG is a calculation of the amount of aggregation and interspersion of all patch types within the landscape, on a scale from 0 to 100 (see McGarigal et al. 2012 for more information). If a landscape has a CONTAG value of 100, all patch types are maximally aggregated, thus signifying a lower degree of fragmentation.

Seasonal home ranges were intersected with a high-resolution land cover map of the region (Diamond et al. 2014) in ArcGIS 10.2 (ESRI 2011), and imported into FRAGSTATS.

Land cover classification for the area was initially divided into 40 categories, based on a variety of environmental variables. I grouped these classifications into 13 categories thought to be more relevant to black bears for use in FRAGSTATS (Table 2.1; Elliott 2015, David Diamond, personal communication). ED and CONTAG were calculated for 17 male home ranges and 72 female home ranges on the FRAGSTATS-designated 'landscape level', using the 8-cell neighborhood rule with open water as a background variable (McGarigal et al. 2012). ED and CONTAG results were separately compared to an equal number of random circular home ranges. Random home range areas were equal in area to the appropriate sex's average seasonal home range, allowed to overlap, and prohibited from going outside of the study area boundaries. The distribution of actual and random fragmentation estimates were tested for normality with the Shapiro-Wilk normality test. Comparisons between randomly drawn home ranges and actual male and female home ranges and between male actual home ranges and female actual home ranges were conducted with the Mann-Whitney *U*-test for nonparametric data. While there is an inverse relationship between CONTAG and ED (McGarigal et al. 2012), both metrics proved useful for different Mann-Whitney *U*-test comparisons and were therefore both reported.

Results

Home range analysis

Spatial data from the 23 bears resulted in an MCP-delineated study area of 4587.2 km^2. Ten autumn home ranges (171.0 km^2 ± 108.2) and 7 summer home ranges (265.6 km^2 ± 153.4) were estimated for males, with 125.2 ± 40.3 and 131.0 ± 45.3 locations, respectively. Thirty-four autumn home ranges (75.4 km^2 ± 57.1) and 38 summer home ranges (99.4 km^2 ± 44.2) were estimated for females, with 139.2 ± 47.9 and 157.3 ± 53.3 locations, respectively. Female home ranges outnumbered male home ranges because the initial purpose of collaring black bears in the region was to estimate demographics and population growth. During summer and autumn, males had significantly larger 95% isopleth home ranges than females ($p = 0.002$, for both comparisons, Table 2.2). Male home ranges did not differ significantly between summer and autumn ($p = 0.133$). Female summer home ranges were significantly larger than female autumn home ranges ($p = 0.005$). Males had significantly larger core areas (50% isopleth) than females in both the autumn ($p = 0.018$) and summer ($p = 0.014$). Seasonal differences for male core areas were not statistically significant ($p = 0.109$), whereas female summer core areas were significantly larger than female autumn core areas ($p = 0.002$).

PHO analysis was conducted with a total of 240 instances of home range overlap (Table 2.3). On average, black bear seasonal home ranges had 2.9 ± 1.5 instances of overlap with another individual. Males displayed significantly less overlap than females ($p = 0.009$), and adult males displayed significantly more overlap than sub-adult males ($p = 0.014$). All other comparisons were not statistically significant.

Fragmentation analysis

Fragmentation analysis was conducted for autumn, summer and both seasons combined, although conclusions were based on the combined dataset because there was no evidence of seasonal differences (Table 2.4). Male home ranges, on average, were significantly more fragmented than female home ranges based on ED values ($p = 0.029$). CONTAG values between males and females were not significantly different ($p = 0.491$). Male home ranges were neither more nor less fragmented than random home ranges for both metrics. Conversely, female home ranges were significantly less fragmented than random home ranges (ED: $p < 0.001$, CONTAG: $p < 0.001$).

Discussion

Understanding how animals use space and resources in newly recolonized, human-altered habitats is critical because animals in a fragmented landscape might behave differently than conspecifics in a more contiguous landscape. Historically, studies addressed the responses of wildlife to having their continuous habitat fragmented. Many species have been assessed, including but not limited to bobcats, coyotes, gray foxes and mountain lions (Crooks 2002, Riley et al. 2003). With this study, I am investigating how a recolonizing species inserts itself into a fragmented habitat. Estimating space use by individual animals can help predict the likelihood of recolonization of a self-sustaining black bear population (Karelus et al. 2016). Individuals' home ranges can be used as indicators of habitat suitability, because smaller home ranges are often associated with productive habitats with substantial resources (Lindzey and Meslow 1977, Oli et al. 2002, Tucker et al. 2008). Conversely, a lack of suitable habitat across the landscape oftentimes leads to larger average home ranges (Seibert 1989, Clark 1991, Riley et al. 2003, Mitchell and Powell 2008).

Within the Oklahoma Ozark population, there is a significant difference in home range size between male and female black bears, as commonly observed in other populations (Dahle and Swenson 2003, Koehler and Pierce 2003, Pelton 2003, Carter et al. 2010, Immell et al. 2014). This is partially due to enlarged male home ranges during mating season, as well as females' tendency toward philopatric behavior (Lindzey and Meslow 1977, Lewis et al. 2014, Lewis and Rachelow 2011). Females in our study had larger summer home ranges than autumn home ranges. This could be due to more dispersed or lower amounts of food available in the summer than in the autumn, creating the need for larger home ranges (Lyda et al. 2007, Moyer et al. 2007). Food availability is commonly thought to be one of the main drivers of home range size differences (Koehler and Pierce 2003, Lyda et al. 2007). The onset of hard mast availability in the autumn as well as the onset of hyperphagia tends to decrease home range size (Lyda et al. 2007, Nagy and Haroldson 1990).

Male home ranges were not significantly different on a seasonal scale. We thought that male summer home ranges would be larger than autumn home ranges, as individual males are forced to travel longer distances to find mates (Lewis and Rachlow 2011). The lack of a seasonal difference was especially surprising given that the sex ratio for the Ozark population was 2.4M:1F (Lyda et al. 2016), creating a potential shortage of viable mates for the males. Large amounts of variance among male home range sizes and annual fluctuations in resource availability, combined with our small sample size of male home ranges, may have obscured seasonal differences in home range size (Moyer et al. 2007, Pfander 2016).

Compared with other black bear populations nationwide, the Oklahoma Ozark black bear home range averages were generally larger (e.g. Lyons et al. 2003, Moyer et al. 2007, Karelus et al. 2016), although comparison between studies is difficult due to differences in the study areas themselves. Female home ranges were significantly larger in the Oklahoma Ozark region than the nearby Ouachita Mountain region of Oklahoma ($p < 0.0001$ for both seasons; Yaklin 2017, Pfander 2016) and Arkansas Ozark Mountains (Clark 1991). Home range estimation methods were standardized between the Oklahoma Ozark region and Ouachita region studies, so differences in home range may reflect differences in habitat quality related to land cover composition and/or differences in the degree of fragmentation by roads and human activity (Clark et al. 1994, Yaklin 2017).

The density of male and female black bears is in part determined by space use and home range overlap (Clark 1991). The degree to which black bears are willing to overlap their home ranges with other bears may indicate the density bears will achieve in a given area and therefore may help determine the recolonization potential of the Oklahoma Ozark region. In 2011 – 2016, an average of 38% of any given female black bear's home range overlapped with one or more other black bears. This may not be the maximum but suggests that at least this level of overlap could occur in similar habitats in the region. Female black bears in this area are mostly found in or around Cookson Wildlife Management Area in Cherokee and Adair counties. At some point, if more females were to recolonize the Oklahoma Ozark region, resources found in high quality habitat near Cookson will be at a premium and we would expect female bears to settle in other patches of suitable habitat (Lindzey and Meslow 1977, Oli et al. 2002).

Males exhibited lower degrees of home range overlap than females. Sub-adult males had even lower degrees of home range overlap, which may be a result of sub-adults being outcompeted for higher-quality land by full-grown adult male bears, and being forced further from the epicenter of the population (Pelton 2003, Carter et al. 2010).

The sensitivity to fragmentation by female black bears in the Oklahoma Ozarks is essential information for management planning, as females are the driving force behind black bear population growth (Moyer et al. 2007, Mitchell et al. 2009, Lewis et al. 2014). Female black bear home ranges were significantly less fragmented than randomly drawn home ranges of an average female home range size, based on both the density of edge and amount of contagion.

This could partially be due to a correlation between ED and human-altered habitat, which may be actively avoided by black bears (Carter et al. 2010, Chapter 2).

Male black bear home ranges did not show a significant relationship with fragmentation. This indicates that males are neither seeking out nor avoiding habitat edges created by natural or anthropogenic processes. The fact that they are not avoiding fragmentation could represent tolerance of a fragmented landscape in exchange for access to higher-quality habitat patches. By extending their home ranges over a fragmented landscape, they can increase total food availability. It is also possible that males are at less risk than females, or their dependent young, from exposure to mortality associated with moving through a fragmented landscape, especially non-forested patches.

Whether fragmentation is a hindrance to movement or a boon to population growth and expansion can change based on the species, as well as how land cover types are defined (McGarigal et al. 2012). The sensitivity of female black bears to fragmentation in the Oklahoma Ozark region could be problematic for long term recolonization of this area, and could negatively impact the overall likelihood of the establishment of a self-sustaining black bear population. Vehicle collision data and bear sightings should be closely monitored outside the core habitat area to determine whether females are able to safely or efficiently transition from the Oklahoma Ozark Mountains through the lower-quality habitat to other higher-quality patches.

Conclusion

Understanding how fragmentation could affect population growth and recolonization is essential to predicting the future of this population (Chapron et al. 2014). Home range size, home range overlap, and sensitivity to fragmentation may be important indicators of the impact of anthropogenic alterations to the landscape. Female black bears in this population have larger home ranges than those in another eastern Oklahoma population, potentially due to fragmentation or lower habitat quality. As fragmentation increases, land available to black bears in the Oklahoma Ozarks decreases in quality, particularly for females. Because females are the limiting sex in this population, further decreases in habitat availability or increases in fragmentation would negatively affect the potential for this population to grow.

Future fragmentation analysis could include calculating contrast-weighted edge density, a metric that assigns different weights or severities to each type of edge (McGarigal et al. 2012), because black bears most likely have different perceptions of different kinds of edges (i.e. roads-to-deciduous forests vs. evergreen forests-to-deciduous forests). Continuing to study these black bears will lead to a more accurate assessment of recolonization and is essential for future management decisions regarding the population.

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Tables and Figures

Table 2.1: Land cover type reclassification used in fragmentation analysis. Forty original classes were reclassified to 12 (Diamond et al. 2014, David Diamond, personal communication), plus open water as the background variable (McGarigal et al. 2012). Land cover type classification was used to calculate edge density (ED) and contagion (CONTAG) within seasonal black bear home ranges.

Original ID	Original Description	New ID	New Description
14407	Arkansas Valley: Prairie/Pasture	8	Pasture/prairie
9000	Barren	1	Barren
504	Crosstimbers: Post Oak Forest	3	Deciduous Woodland
503	Crosstimbers: Post Oak - Eastern Red Cedar	7	Evergreen Forest and Shrubland
506	Crosstimbers: Young Post Oak Woodland	13	Shrubland
9327	Disturbed Soil Pasture	8	Pasture/prairie
14717	Eastern Great Plains: Herbaceous Wetland	8	Pasture/prairie
9600	Open Water	11	Open Water
2027	Osage Plains: Tallgrass Prairie/Pasture	8	Pasture/prairie
13103	Ozark-Ouachita: Dry Mixed Woodland	10	Mixed Evergreen-Deciduous Forest
13104	Ozark-Ouachita: Dry Oak Woodland	3	Deciduous Woodland
13106	Ozark-Ouachita: Dry Oak Woodland Young Regrowth	13	Shrubland
13003	Ozark-Ouachita: Dry-Mesic Mixed Forest	10	Mixed Evergreen-Deciduous Forest
13004	Ozark-Ouachita: Dry-Mesic Oak Forest	4	Moist Oak Forest
13006	Ozark-Ouachita: Dry-Mesic Oak Woodland Young Regrowth	13	Shrubland
9117	Ozark-Ouachita: Pasture/Prairie	8	Pasture/prairie

13500	Ozark-Ouachita: Riparian Barrens	1	Barren
13506	Ozark-Ouachita: Riparian Deciduous Shrubland	6	Riparian Forest
13515	Ozark-Ouachita: Riparian Evergreen Woodland and Shrubland	6	Riparian Forest
13504	Ozark-Ouachita: Riparian Hardwood Woodland	6	Riparian Forest
13517	Ozark-Ouachita: Riparian Herbaceous Wetland	9	Herbaceous Wetland
13503	Ozark-Ouachita: Riparian Mixed Woodland	6	Riparian Forest
13403	Ozark-Ouachita: Shortleaf Pine - Oak Forest	10	Mixed Evergreen-Deciduous Forest
9301	Pine Plantation	7	Evergreen Forest and Shrubland
9307	Row Crops	12	Row Crops
9206	Ruderal Deciduous Shrubland and Young Woodland	13	Shrubland
9104	Ruderal Deciduous Woodland	3	Deciduous Woodland
9103	Ruderal Eastern Redcedar - Mixed Woodland	10	Mixed Evergreen-Deciduous Forest
9115	Ruderal Eastern Redcedar Woodland and Shrubland	7	Evergreen Forest and Shrubland
14815	South Central Interior: Bottomland Eastern Redcedar Woodland and Shrubland	7	Evergreen Forest and Shrubland
14804	South Central Interior: Bottomland Hardwood Forest	2	Bottomland Hardwood Forest
14817	South Central Interior: Bottomland Herbaceous Wetland	8	Pasture/prairie

14803	South Central Interior: Bottomland Mixed Forest	10	Mixed Evergreen-Deciduous Forest
14806	South Central Interior: Bottomland Shrubland and Young Woodland	13	Shrubland
14800	South Central Interior: Bottomland Barrens	1	Barren
15115	South Central Interior: Riparian Eastern Redcedar Woodland and Shrubland	6	Riparian Forest
15104	South Central Interior: Riparian Hardwood Woodland	6	Riparian Forest
14806	South Central Interior: Riparian Shrubland and Young Woodland	13	Shrubland
9410	Urban High Intensity	5	Urban
9411	Urban Low Intensity	5	Urban

Table 2.2: Seasonal home range values by sex in square kilometers, as well as both sexes combined. Core area (50%) and 95% isopleth home ranges were calculated in Geospatial Modeling Environment (Beyer 2012) as kernel density estimations, with Least Squares Cross Validation as the smoothing parameter.

	Male		**Female**	
	50%	**95%**	**50%**	**95%**
Summer	63.6 ± 40.5*	265.6 ± 153.4*	23.6 ± 12.1*^	99.4 ± 44.2*^
Autumn	31.0 ± 22.0*	171.0 ± 108.2*	15.3 ± 12.7*^	75.4 ± 57.1*^

* value is significantly different than other sex's similarly-classified value

^ value is significantly different than other season's value, within sex

Table 2.3: Mean percent home range (95% isopleth) overlap for males and females, split into age classes and seasons.

	Male			**Female**		
	Combined	**Autumn**	**Summer**	**Combined**	**Autumn**	**Summer**
Sub-adult	21.1% ^*	17.9% *^	23.2%	38.2% *	38.6% *	37.8%
Adult	44.5% ^	42.0% ^	48.0%	37.6%	42.3%	34.0%
Combined	24.1% *	22.1% *	25.6%	38.3% *	40.3% *	35.9%

* value is significantly different than other sex's similarly-classified value

^ value is significantly different than other age class's value, within sex

Table 2.4: Fragmentation analysis output calculated in FRAGSTATS v4.2.1 (McGarigal et al. 2012). Edge density (ED) and contagion (CONTAG) within seasonal black bear home ranges was calculated and averaged within seasons as well as combined, for males and females. Random home ranges were created to be equal in area to the appropriate sex's average seasonal home range, were allowed to overlap, and were not allowed to include space outside of the study area boundaries. ED output is measured in meters per hectare and CONTAG output is measured as a percent contagion index. Statistical comparison was only calculated for combined values.

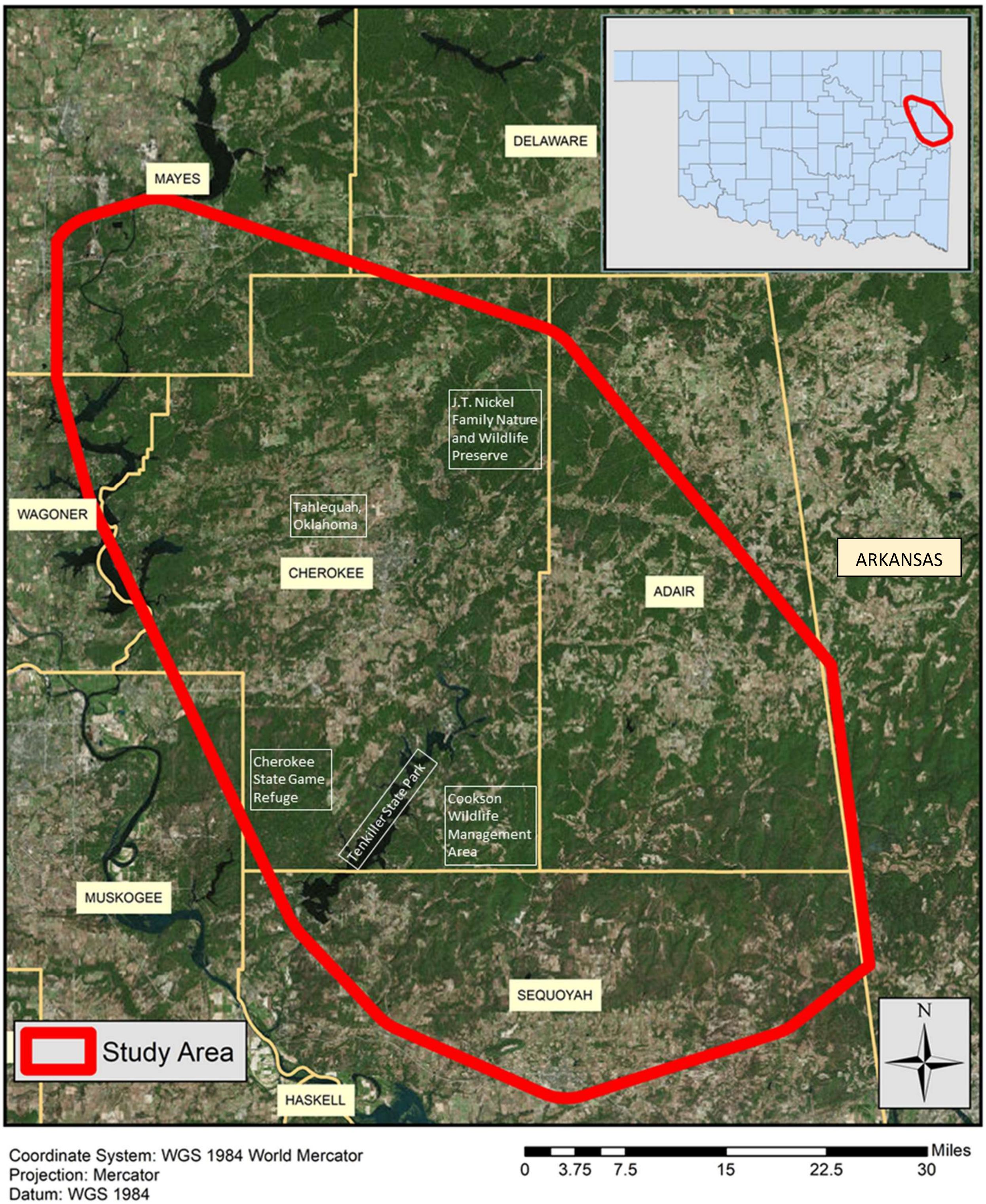
	Male		**Female**	
	ED	**CONTAG**	**ED**	**CONTAG**
Combined	119.9 ± 13.8*	66.8 ± 3.0	111.5 ± 17.7*^	67.6 ± 1.7^
Summer	114.1 ± 8.7	67.5 ± 2.1	111.2 ± 18.2	67.4 ± 1.7
Autumn	123.9 ± 15.6	66.2 ± 3.5	111.8 ± 17.3	67.8 ± 1.7

	Random Male		**Random Female**	
	ED	**CONTAG**	**ED**	**CONTAG**
Combined	115.4 ± 13.1	65.2 ± 3.6	125.9 ± 26.4^	64.5 ± 3.2^
Summer	113.8 ± 12.2	66.2 ± 3.1	120.3 ± 19.4	64.8 ± 3.0
Autumn	116.6 ± 14.2	64.5 ± 4.0	132.1 ± 31.7	64.2 ± 3.5

* value is significantly different than other sex's similarly-classified value

^ value is significantly different in respect to the comparison between random home range and actual home range

Figure 2.1: Study area was determined by estimating a 100% minimum convex polygon of all location estimates obtained from radiomarked black bears in the Oklahoma Ozarks region in 2011–2016. Areas of particular interest are labeled, as well as county names and demarcations.



CHAPTER III

RESOURCE SELECTION BY AMERICAN BLACK BEARS IN THE OKLAHOMA OZARKS REGION

Introduction

Identifying the environmental characteristics that most strongly impact behavior of an animal population is a fundamental pursuit in ecology and natural resource management (MacArthur et al. 1966). Understanding how a human-dominated landscape affects the viability of a recolonizing population is especially critical if the extirpated species is returning to a significantly altered part of their historical range (Beckmann and Berger 2003, Hiller et al. 2015). If a species is unable to adapt to the level of anthropogenic change within their original habitat, recolonization of the region could stagnate (Chapron et al. 2014). After being extirpated from much of their historical range due to overharvest and habitat loss, effective wildlife management policy has allowed the American black bear (*Ursus americanus*) to recolonize historic, but oftentimes highly-altered, areas (Smith and Clark 1994). The impact of anthropogenic encroachment on black bear resource selection has been extensively studied across their geographic range (e.g. Carter et al. 2010, Hiller et al. 2015), and is especially important for future conservation management planning of a species frequently associated with human-wildlife conflict (Baruch-Mordo et al. 2011). Quantifying the importance of landscape and habitat features associated with recolonization provides valuable details regarding the habitat needs and spatial ecology of the population (Benson et al. 2016).

Resource selection functions (RSFs) can be useful wildlife management tools for land-management planning, population viability analysis, and human-wildlife conflict predictions (Boyce et al. 2002). The output of RSFs can help effectively manage and conserve populations of many species across taxa (Manly et al. 2002). However, spatial variation in the distribution and abundance of numerous resources included in an RSF analysis can create individual variation in resource selection (Benson et al. 2016). In the case of black bears, individuals will select land cover types with relatively plentiful food sources, across studies. However, their relationship with humans is more difficult to ascertain.

Large carnivore species, including black bears, behave under a trade-off between mortality risk and foraging success known as the theory of ideal-free distribution (Fretwell 1972) that is often related to anthropogenic features or activity (Frid and Dill 2002, Riley et al. 2003, Knopff et al. 2014, Johnson et al. 2015). Land cover type selection is theoretically the outcome of decisions that balance a high degree of resource richness with a low perceived risk of mortality (Fretwell 1972, Frid and Dill 2002). Acquiring resources such as food, cover or territory often comes at the cost of increased perceived risk, either from anthropogenic sources (i.e. road mortality or hunting) or otherwise (i.e. intraspecific or interspecific competition; Frid and Dill 2002). Higher quality habitats most likely provide black bears with essential resources while not exposing the bears to increased levels of risk. This dynamic trade-off system is affected by many variables, and can be difficult to accurately assess. RSFs help quantify this complex trade-off, providing valuable insight for wildlife and land management (Manly et al. 2002).

Black bears often avoid human activity when natural food availability is high or use of anthropogenic resources is considered too risky (e.g. Hiller et al. 2015). However, black bear selection of anthropogenic features can vary considerably. A population of black bears in Michigan avoided roads due to increased hunting pressure near roadways, as well as the likelihood of a vehicle mortality, but selected for areas near agricultural fields, signaling that this bear population was both avoiding and selecting for human-altered land (Carter et al. 2010). In other areas, black bears may actively select areas of high human use, most likely to take advantage of anthropogenic food sources. Black bears relied heavily on anthropogenic food sources due to a lack of natural food sources in the Elk Mountain range of Colorado (Johnson et al. 2015). Black bears may be using anthropogenic food sources with a low perceived risk, either due to changes in bear behavior or the characteristics of the food source (Beckmann and Berger 2003, Sollmann et al. 2016). Extrinsic sources of individual-level variation in behavior such as resource availability most likely influence black bear resource selection in human-altered landscapes. However, that influence is highly variable from study to study.

The natural expansion of a reintroduced population of black bears in Arkansas century (Smith and Clark 1994) brought the species back to east-central Oklahoma in the beginning of the 21st. Population evaluations conducted in 2016 estimated approximately 77 – 82 individuals, primarily within the Oklahoma Ozark Plateau region (henceforth referred to as the Oklahoma Ozarks, Lyda et al. 2016). It is unclear whether the altered landscape's food sources are able to sustain a population of bears, as well as whether bears will select, avoid, or have no significant relationship with anthropogenic features. The population is not currently hunted, although there is a hunted black bear population in southeast Oklahoma (Pfander 2016). If this population continues to grow, the frequency of human-black bear conflicts, such as intrusions by black bears into urban areas, damage to deer feeders, bee hives and other property, may increase. Information concerning the relationship of black bears to natural and anthropogenic features and resources is needed to successfully manage the population as it colonizes a human-dominated landscape.

The goal of this research was to determine the importance of anthropogenic features in resource selection by black bears in this recolonizing population. Specifically, this study addressed several questions: 1) Within the study area as well as individual black bear home ranges, what natural and anthropogenic landscape features were selected or avoided? 2) Were there significant differences between male and female black bears? 3) Are there vacant areas of high quality habitat into which the population could expand? These results are important because they provide neoteric information about environmental conditions that enable successful recolonization of black bears in a human-dominated landscape. The degree to which anthropogenic food sources or other variables attract black bears to close proximity with humans will likely predict the amount of human-black bear conflict in the area (Beckmann and Berger 2003). This research will also help to predict potential areas of range expansion by the population, and will be valuable for managers attempting to conserve healthy populations of black bears, while minimizing conflict along wildland-urban gradients.

Methods

Study Area

The study area focuses on parts of seven counties in east-central Oklahoma: Cherokee, Sequoyah, Adair, Mayes, Delaware, Wagoner and Muskogee (Figure 3.1). The majority of the land is privately owned. However, some patches of public land are included in the study area, notably the 59.6 km^2 Cookson Wildlife Management Area. The western edge of the study area is characterized by numerous natural areas with high volumes of human recreation, such as Tenkiller State Park and Snake Creek Cove Campground (U.S. Army Corps of Engineers). The study area consists primarily of oak-hickory forest (*Quercus* spp., *Carya* spp.), with short-leaf pine (*Pinus echinata*) in small amounts at higher elevations. Soft mast species in the area include seasonal fruiting species such as blackberries (*Rubus* spp.), black cherries (*Prunus serotine*), and persimmons (*Diospyros virginana*). Anthropogenic food sources, such as corn feeders for deer and bee hives, are also commonly found throughout much of the study area and are known to supplement the diet of some individuals in the Oklahoma Ozark black bear population (Artz 2016). The eastern part of the study area contains the Ozark Mountains, which cross from Arkansas into Oklahoma. Land use by humans within the study area is largely recreation-related, with a focus on hunting. Prairie and pastureland substantially outnumber row crop acreage, and can be found in varying patch sizes throughout the region. The region is latticed with numerous small and medium-sized roads and trails, as well as a few large highways and railroads. Human population centers within the study area include towns and small cities with populations ranging from approximately 4,000 to 17,000 people.

Capture and Handling

Black bear live-trapping from 2011-2016 used full enclosure barrel traps and culvert traps baited with pastries, sardines, and feed corn. Live trapping teams maintained trap lines of varying number of traps within the study area for each trapping season. Trap line locations were located in areas of known black bear occurrence, and were based on land owner permissions, camera trap data (Lyda et al. 2016) and a hair snare study on this population conducted from 2014 – 2016 (Artz 2016). Captured bears were sedated with a 2:1 mixture of Telazol and Xylazine at a dosage rate of 4.8 – 7.0 mg/kg (Clark and Smith 1994), administered intramuscularly with a pole syringe (Clark 1991). We marked captured bears with plastic ear tags and a lip tattoo with corresponding, unique identifying numbers. Tissues removed to attach ear tags were reserved for future genetic analysis. We gave captured bears an injection of 2-4 mg/kg of Carprofen for pain management, and collected a vestigial first upper premolar for aging, as well as a hair sample for DNA analysis. Advanced Telemetry Systems G2110E Iridium GPS location collars (Advanced Telemetry Systems [ATS], Asanti, MN) were placed on select bears throughout all capture seasons to collect data at variable schedules. Trapping continued throughout the length of the project to catch new individuals or replace and refurbish collars that required maintenance. All animal handling procedures were approved by Oklahoma State University Institutional Animal Care and Use Committee (IACUC) Protocol #AG-13-6.

Resource Selection Functions

Resource selection of black bears in the Oklahoma Ozark region was investigated following Johnson's (1980) 2nd and 3rd orders of selection, comparing used to available data points to estimate the relative probability of the use of resource features in relation to their availability (Manly et al. 2002, Benson et al. 2016). A multi-scale analysis is essential to accurately assess resource selection (Boyce et al. 2002, Karelus et al. 2016). Selection on the 2nd order (Johnson 1980) deems all land within the "study area" available to black bears, thus addressing selection within the Oklahoma Ozark region. Resource selection functions on the 3rd order (Johnson 1980) ask a similar question, but limit available land to within the individual black bear's home range. Second order analysis determines where black bears select to place their home ranges within the study area, whereas 3rd order analysis focuses on what specifically within each home range is being selected. Black bears have displayed different selection behaviors within home ranges than at the landscape scale (Ciarniello et al. 2007, Reynolds-Hogland and Mitchell 2007, Yaklin 2017). Therefore, conducting analyses on both orders provides a more complete understanding of how environmental and anthropogenic variables affect black bear ecology (Johnson 1980).

For both orders of analysis, used points were sourced from spatial data from 23 GPS-collared black bears (10M, 13F). These points were subsampled to a maximum daily occurrence rate of two locations ≤ 12 hours apart, as a method of minimizing spatial and temporal autocorrelation (Boyce et al. 2002). All data points were associated with year and season values, as well as a unique bear ID. Seasons were based on local black bear ecology and food availability: winter (January – April), summer (May – August) and autumn (September – December; Lyda et al. 2007). Winter data points consisted primarily of hibernation data with a low fix rate, and were excluded from the resource selection functions.

Available points for landscape-scale analysis were confined to a 100% minimum convex polygon (MCP) of the used points (Hiller et al. 2015) and randomly generated in ArcGIS 10.2 (ESRI 2011). The number of available points was set equal to the number of used points

(Johnson et al. 2006, Northrup et al. 2013, Hiller et al. 2015, Lesmerises and St. Laurent 2015). Season, year and bear ID were randomly assigned to all available points in proportion to values in the used points database. For home range-scale analysis, an equal number of randomly-generated available points were confined to each individual's seasonal home range (Chapter 1). Home ranges were created in Geospatial Modeling Environment (Beyer 2012) as kernel density estimations (KDE) at the 95% isopleth, with commands *kde* and *isopleth*. Available points were given matching season, year and bear ID values to the specific home range.

Seven habitat variables were tested for selection on both scales. Elevation and slope were estimated from a 30-m resolution digital elevation model (DEM). A Terrain Ruggedness Index (TRI; Riley et al. 1999) was created from the DEM as a measure of the difference in elevation between adjacent cells. Block population density, the smallest geographic unit of population measurements for which the Census Bureau publishes data, (U.S. Census Bureau 2010*a*) was used as a means of estimating human population. Distance of each location to the nearest large (i.e. interstates, national and state highways, high-traffic streets) and small (i.e. rural roads, private service roads, vehicular trails and private driveways) road (U.S. Census Bureau 2010*b*) was calculated in ArcGIS 10.2 using the *near* tool. Land cover type classification was based on a previously collected and ground-truthed data layer released by the Oklahoma Department of Wildlife Conservation (Diamond et al. 2014). Forty land cover types found within the study area were reclassified into 6 classes: mixed hardwood forest/regrowth, deciduous woodland, moist oak forest, riparian forest, pasture/prairie, and anthropogenic (Table 3.1). Reclassifications were created by combining land cover types with ecological similarities (Table 3.2; Elliott 2015, David Diamond, personal communication). The way land cover categories are combined is potentially important as it may substantially affect model results (Alldredge and Griswold 2006).

However, land cover classification clumping was necessary to simplify data and assist in model convergence while still taking advantage of the in-depth land cover classification map in the final resource selection results. A degree of specificity was allowed when distinguishing between different types of forest, as the amount and types of food availability, cover and other natural resources change based on factors such as species composition, soil type and landform variation (e.g. Clark et al. 1994). Dividing forest into multiple categories theoretically helped certain types of forests stand out as being selected for or against, based on their individual characteristics. The anthropogenic land cover type contained low- and high-intensity urban, barren, and row crops. Open water was considered unavailable to black bears, and removed from the study. Pasture/prairie was used as the reference land cover type for all land cover type comparisons.

All environmental variables were tested for multicollinearity using the *cor* command in R v3.4.3 (R Core Team 2017) with the Pearson method. Any pair of independent variables with $|r| > 0.7$ was considered correlated (Nielsen et al. 2002, Hiller et al. 2015). Slope was highly correlated with TRI ($|r| = 0.925$) and was not used in modeling, although that was the only instance of high correlation. Human population density was log transformed, while TRI and elevation were standardized via z-transformation, to better facilitate model convergence (Schielzeth 2010). Large roads were not included in either 2nd or 3rd order models because of the infrequency of major highways in the study area (Benson et al. 2016). Small roads and large roads were combined into one distance to roads layer, and standardized via log transformation. Additionally, sex was added as a factor to determine whether black bears display any significant sex-specific resource selection patterns in our study area.

For both 2nd and 3rd order analysis, 32 *a priori* models were developed in an information-theoretic approach. Generalized linear mixed models (GLMMs) were created with bear ID and year as random effects in each model, with year nested in ID. Including individual bears as random effects alleviated the lack of independence between an individual's used locations (Gillies et al. 2006, Benson et al. 2016). The random effect of year accounted for any effect annual changes in climate or food availability had on resource selection. Models were run in the R package 'lme4' using the *glmer* command with a binary response variable (0 = available, 1 = used). Model selection was conducted with Akaike's Information Criterion for small samples (AICc; Akaike 1973, Burnham and Anderson 2002). Models with ΔAICc values of < 2 units from the top model were considered competitive (Burnham and Anderson 2002, Simek et al. 2015). Second order models were analyzed on an annual scale (excluding the winter hibernation period), whereas 3rd order models were calculated separately for summer and autumn. Evidence suggests that black bears have different uses for land cover between the two seasons on a home range-scale (Unsworth et al. 1989, Yaklin 2017).

Multiple studies have found that black bears are not affected or are even positively selecting for roads (Brody and Pelton 1989, Lyda et al. 2007). Other studies have found that black bears select against roads (Clark 1991, Reynolds-Hogland and Mitchell 2007, Simek et al. 2015), or select against roads specifically due to a hunting season (Carter et al. 2010, Hiller et al. 2015). The Oklahoma Ozark black bear population is not currently hunted. While distance to roads was included in the RSF analyses, this aspect of space use warranted further post-hoc analysis. Fragmentation analysis results showed a significant difference between male and female sensitivity to fragmentation (Chapter 1), and roads can be an important cause of fragmentation (Ditmer et al. 2015). Used and available distances from the nearest road as previously described were tested for normality with the Anderson-Darling test (Anderson and Darling 1954) and compared with the Mann-Whitney *U*-test. Male and female used points were separated and tested against their respective available points. Finally, male and female used points were directly compared to determine whether there was a significant difference in the relationship to roads between sexes.

Results

Resource selection, 2nd order

Black bears exhibited selection at both 2nd and 3rd orders. However, the impact of these variables changed between scales. At the 2nd order, black bears were selective with respect to land cover type, distance to roads, terrain ruggedness, elevation, and human population density (Table 3.3). A competitive model included the same variables with the addition of sex, suggesting there might be some small differences in resource selection between males and females, although not enough to substantially improve model fit. Bears selected strongest for riparian forest and moist oak forest and weakest for pasture/prairie land cover types (Table 3.4). Bears selected for greater distances to roads, and against areas of higher human population density. Areas of higher elevation and terrain ruggedness were also selected.

Probability of Use Mapping

I created a relative probability of use map based on top model output in ArcMap by dividing predictive values into five distinct quantiles (Figure 3.2; Carter et al. 2010). This map was extended further north and south within the state of Oklahoma to identify additional areas of potentially high-quality habitat (Figure 3.3). However, predictive ability of the model decreases outside of the study area as the output involved was based strictly on values confined within the original study area.

The probability of use map indicates that the relatively contiguous hotspots of higher-quality habitat inside the study area are found in Cherokee and Adair counties, in the J.T. Nickel Family Nature and Wildlife Preserve, Cherokee State Game Refuge, and the Oklahoma Ozark Mountains. Higher-quality habitat clumps within the study area frequently appear separated by areas thought to have high levels of human activity such as roads or lower-quality habitat, such as pasture/prairie and human-impacted land. This creates a patchwork array of desirable land that black bears will need to contend with to move through the landscape. As of early 2017, there were no radio-collared bears in many habitat areas designated as high or medium-high quality outside of the core area. Trapping for uncollared bears has focused almost exclusively within the Ozark Mountains, with little trapping in other parts of the region. The results of this study will guide the selection of new areas in which to focus trapping efforts in the ongoing research.

By overlapping the probability of use map with each female home range, I found an average of 59.7% high or medium-high quality land within the home range boundaries. This was 19.7% more than the availability of higher-quality land in relation to the study area. Higher-quality habitat exists outside of the borders of the study area, although the majority of this is to the north, relatively far from the core area in the Ozark Mountains. South of the study area is largely low-quality and includes I-40, a major roadway that could be a substantial barrier to movement (Brody and Pelton 1989, Dixon et al. 2006).

Resource Selection, 3rd order

During summer, bears were selective with respect to land cover type, elevation, distance to road and human population density (Table 3.5). Terrain ruggedness was considered a 'pretender variable' because its addition led to minor increases in AICc value while increasing model complexity. The top land cover types selected were riparian forest and moist oak forest (Table 3.6). However, the anthropogenic land cover type was considered the third-most selected category by bears. As with the 2nd order analysis, greater distance from road was selected, while higher human population densities were selected against. Black bears selected higher elevations in the summer.

For the autumn season, black bears were selective with respect to land cover type, terrain ruggedness, distance to road and human population density (Table 3.7). There were no other models that were considered statistically competitive. Riparian forest and moist oak forest remained the top land cover categories selected by the bears (Table 3.8). The anthropogenic category was less selected than in the summer relative to the other land cover categories. As with the 2nd order analysis, greater distance from roads was selected for while greater human population density was selected against. Greater terrain ruggedness was also selected for in the autumn, while elevation was not included in the top model

Distance to roads

As shown in the resource selection functions, combinations of habitat variables better explained habitat selection versus a solitary variable. However, after determining different sensitivities to fragmentation by sex (Chapter 1), I thought that the sexes would differ in avoidance of roads, which can be a major cause of fragmentation. Such a relationship was possibly masked by other variables in the more complex RSF. Results showed that both males and females were less likely to use areas closer to roads than randomly plotted available values ($p < 0.001$ for both). On average, males (701.2 m ± 447.0) also used areas significantly closer to roads than females (813.2 m ± 561.9, $p < 0.001$).

Discussion

Resource selection by black bears in the Oklahoma Ozarks region was influenced by multiple environmental and anthropogenic variables. Specifically, bears were selecting areas within the study region that had high amounts of food availability and cover, and low amounts of human activity. Understanding the specifics behind this finding is critical for creating informed management decisions, especially if the recolonizing bear population moves further into the region.

Black bears in the Oklahoma Ozarks exhibited the strongest selection for riparian forest and moist oak forest land cover types, most likely due to the high levels of food availability and cover in those classifications. Riparian forest is found alongside first and second order streams and is commonly associated with high species richness and cover (Naiman et al. 1993). Stream gradient in riparian forest in the study region is relatively high, with sycamores (*Platanus* spp.), river birch (*Betula nigra*), sweetgum (*Liquidambar styraciflua*), maples (*Acer* spp.), oaks (*Quercus* spp.), and hazel alder (*Alnus serrulata*) being the most common trees (Diamond et al. 2014, Elliott 2015). Selection by black bears for riparian forest is often found in studies that contain that land cover type (Lyons et al. 2003, Latham et al. 2011, Johnson et al. 2015, Karelus et al. 2016), and is often attributed to the high amounts of food availability and cover provided by a diverse list of hard and soft mast-producing species.

Moist oak forest is dominated in the study region by many oak and hickory (*Carya* spp.) varieties, as well as sugar maple (*Acer saccharum*) in the most mesic areas (Diamond et al. 2014, Elliott 2015). A diverse undergrowth, including flowering dogwoods (*Cornus florida*), sassafras (*Sassafras albidum*) and blackberry (*Rubus* spp.), adds to food availability and cover within the land cover type (Diamond et al. 2014, Yaklin 2017). As with riparian forest, moist oak forest or similar land cover types are selected by other populations of black bears throughout the country (Hellgren et al. 1991, Clark et al. 1994, Lyons et al. 2003, Lyda et al. 2007, Lesmerises and St. Laurent 2017).

The least-selected land cover types were pasture/prairie and anthropogenic, most likely due to lower quality food availability and cover. Plant species found in these land cover types are not typically sought after by black bears, unless food availability is remarkably scarce (Johnson et al. 2015). Pasture/prairie may provide a small amount of food for black bears soon after den emergence but does not appear to provide other resource benefits.

Recolonizing a human-dominated landscape comes with costs and benefits for predators. Black bears may be attracted to high-quality anthropogenic food, but that may expose them to greater mortality risk and human-wildlife conflict. There is a significant amount of discussion as to whether black bears are using anthropogenic food found in urban areas, pastures or row crops as a food source, or avoiding the land cover types all together (Lyons et al. 2003, Benson and Chamberlain 2007, Karelus et al. 2016, Sollmann et al. 2016). In the Oklahoma Ozark population, urbanized and pasture/prairie land that are likely to contain anthropogenic food sources are avoided in comparison to more natural areas, presumably due to an avoidance of human activity. However, there is substantial evidence pointing to black bear use of feeders for deer in the Ozark and Ouachita regions of Oklahoma (Artz 2016, Pfander 2016, Sara Lyda, personal communication). The use of deer feeders on private land for hunting over bait is legal in the state of Oklahoma and very commonly practiced throughout the study region. Landowners place deer feeders with corn in land cover types frequented by deer (most likely forested with high levels of cover), thereby inadvertently providing a source of anthropogenic food for bears in more natural areas. Additionally, rural landowners dispose of trash in dumpsters that may be placed next to roads, often in forested cover types, which provides another source of anthropogenic food for black bears. This may be increasing the amount of human-caused black bear mortalities due to car collisions, although these are not common occurrences in the region. Mapping precisely where feeders and dumpsters are placed could prove important to future resource selection studies on this population. The location of anthropogenic food sources may be an important driver of resource selection for black bears in this region. Furthermore, these black bears are currently part of a small, low-density population. The use of anthropogenic food sources may change if the population grows.

The selection or avoidance of urban, crop and pasture lands appears to be region dependent. Studies finding that those land cover types are avoided (Lyons et al. 2003, Sollmann et al. 2016, Yaklin 2017) are often set in climate areas that can support land cover types thought to contain more natural food. Studies that find selection for pasture/prairie, agricultural land, urban or barren land are either in relatively harsh climate areas where anthropogenic food sources such as trash, bee hives or fruit trees are required for the population's existence (Johnson et al. 2015), or areas where crop land is producing a food source deemed "worth the risk" of exposure to human activity (Jones and Pelton 2003, Carter et al. 2010, Ditmer et al. 2015, Johnson et al. 2015) either due to convenience or lack of abundant high quality natural food sources. If a recolonizing bear population such as the Oklahoma Ozark population continues to overlap with human development, it is possible that black bear use of anthropogenic food sources will increase, as will their selection for those resources (Johnson et al. 2015, Sollmann et al. 2016). The future overlap between the black bear population and human development could potentially lead to increased human-wildlife conflict and stunt the population's establishment.

As elevation and TRI increase, levels of human access and activity likely decrease whereas cover, food availability and den site quality increase (Apps et al. 2004, Nellemann et al. 2007, Mowat et al. 2013, Sollmann et al. 2016). As expected, higher elevation and higher TRI values were selected, which is typical of other black bear RSF findings (Apps et al. 2004, Nielsen et al. 2004, Nellemann et al. 2007, Sollmann et al. 2016, Yaklin 2017). Additionally, black bears selected for greater distances from roads and areas of low human population density, another common RSF finding (e.g. Carter et al. 2010, Simek et al. 2015). That being said, use or avoidance of roads is a feature of black bear resource selection that differs among studies. Road avoidance is often observed where hunting is allowed within the study area (Hiller et al. 2015, Stillfried et al. 2015, Yaklin 2017). Other studies have found that black bears use roads as travel corridors (Brody and Pelton 1989, Lyda et al. 2007). Whether fear of humans is due to an increased chance of mortality or some other reason, black bears in this population select for areas with lower amounts of human activity based on measured anthropogenic and natural indices, as also found in multiple other studies (Clark 1991, Reynolds-Hogland and Mitchell 2007, Carter et al. 2010, Hiller et al. 2015).

Male and female black bears did not exhibit different selection patterns at the 2nd order selection scale. It may be possible that males and females do not exhibit statistically significant variation in selection at this scale in our study area (Hiller et al. 2015), potentially because higher-quality habitat is rare and heavily fragmented, creating an availability issue – both sexes must make the best of what is available to them to survive. Alternatively, the number of male locations in the data set was approximately 1/5 the number of female locations. Most studies find significant differences in resource selection between males and females (e.g. Benson and Chamberlain 2007), pointing toward the need for an increase in sample size of male spatial data. It is also possible that modeling selection with interaction terms involving sex could yield differences between male and female selection.

The Ozark Mountains are considered the core area for the black bear population in the Oklahoma Ozark region (Artz 2016). Additional areas of high-quality habitat, primarily on public and Nature Conservancy land, exist in the area, but their colonization is dependent upon whether or not there are appropriate travel corridors. Black bears may benefit from travel corridors (either natural or anthropogenic, i.e. low traffic roads) although that is dependent on the local landscape characteristics, most notably habitat fragmentation (Brody and Pelton 1989, Dixon et al. 2006, Kindall and Van Manen 2007).

Black bear population growth is primarily driven by the females within the population (Mitchell et al. 2009, Lewis et al. 2014). As the number of females goes up, the total number of cubs increases per year thereby increasing growth of the population as a whole. Overlapping the probability of use map with each female home range shows that, on average, 59.7% of land within each home range boundary is classified as either high or medium-high quality. The study area consists of 40% high and medium-high quality land, based on the quantile designation for each quality category. For black bear population growth to increase, it may be the case that females must continue to find home range areas in which over half of the habitat is of high/medium-high quality habitat.

Within home ranges, resource selection by the Oklahoma Ozark black bears is also influenced by multiple environmental and anthropogenic variables. In both the summer and the autumn, black bears selected strongest for riparian forest and moist oak forest land cover types, just as in 2nd order selection, further indicating the importance of these cover and food-rich land cover types. Additionally, black bears selected for greater distances from roads and areas of low human population density in both seasons. Similar to 2nd order analysis, this is an indication that black bears were selecting against human-altered parts of their home range. Within the boundaries of their home ranges, black bears selected areas further from roads with lower population densities.

In the autumn, black bears selected the pasture/prairie and anthropogenic land cover types the least, similar to 2nd order selection results. Contrarily, black bears selected the anthropogenic land cover type in the summer more than both deciduous woodland and mixed hardwood forest/regrowth. The reasoning behind this seasonal selection for the anthropogenic land cover type relative to more natural land cover types may be due to the possibility that soft mast-producing species such as blackberries or pokeweed (*Phytolacca americana*) are commonly found on edges created by human development (Clark et al. 1994, Yaklin 2017), thus increasing soft mast availability and therefore selection for the land cover type. This contradicts the human population density and road avoidance results, potentially inferring that areas with less human presence within the anthropogenic land cover type, such as rural homes or farm roads, are being used.

Again, male and female black bears did not exhibit different selection patterns at the 3rd order selection scale. It may be possible that males and females do not exhibit statistically significant variation in selection at either scale. The proportion of male to female locations likely affected the comparison at this scale, as well.

Differences between male and female black bears were observed when distance to roads was separately addressed. Female black bears stayed significantly further away from roads than male black bears. This result was expected as previously-calculated edge density results showed that male home ranges contained higher amounts of edge density than females (Chapter 1), and edge density is thought to directly relate to road density in this study area. While sex may not be a significant factor within the top RSF model, this conclusion is still important for predicting the likelihood of black bear recolonization for the region. If females consider roads hazardous to cross or live near, the amount of available higher-quality land within the study area may be significantly lower than modeled. Road crossing analysis was not conducted due to the infrequency of spatial data collected per day, although it is known that some road crossings must occur for females to have access to enough resources. Dispersing or colonizing females will have to cross multiple small roads and potentially large roads or railroads to go from the core area of activity within the Oklahoma Ozarks to another higher-quality patch. Whether they are willing to take that risk is unknown. Additionally, females were found to be more sensitive to habitat fragmentation than both males and expected values (Chapter 1), which could further hinder expansion of the female segment of the population and, therefore, growth of the population.

Management Implications

Understanding how black bears select resources in the Oklahoma Ozark region allows for the creation of data-driven management practices and policies. My results show that further expansion of the current roadways into forested land would lower overall habitat quality and potentially hinder future black bear recolonization. Areas of high human activity such as cities, towns and pastures should not be considered available to black bears when discussing potential recolonization, although black bears may be taking advantage of anthropogenic food sources such as deer feeders in forested areas. Conservation and land management practices should target riparian forest and moist oak forest, as these are areas of high import to the black bear population. Additionally, wildlife managers can apply the probability of use map to create informed future monitoring efforts. Traplines, hair snares or remote cameras can be placed in high-quality areas that are near known black bear home ranges but do not have collared individuals. Finally, walking transects through different quality areas can be conducted seasonally to assess natural food availability during both the summer and autumn. A better understanding about what is naturally available to black bears may be important when comparing summer and autumn habitat selection (Clark 1991). Future analysis could combine other spatial datasets such as fragmentation and home range analyses as well as anthropogenic food source location information with resource selection function output to calculate recolonization likelihood as variables change over time.

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Tables and Figures

Table 3.1 Variables involved in the resource selection functions, with data type, ranges, and a short description (Diamond et al. 2014, Elliott 2015). Variables were used in 32 *a priori* models to assess resource selection on 2nd and 3rd order (Johnson 1980). Analysis on the 3rd order was calculated on a seasonal scale, whereas 2nd order analysis was calculated with a combined dataset.

Resource Variable	**Type**	**Range (units)**			**Description**
		Combined Seasons	**Summer**	**Autumn**	
Elevation	Continuous	143 – 518 (m)	150 – 506 (m)	143 – 521 (m)	Vertical distance above sea level
Terrain Ruggedness Index	Continuous	0 – 199.5 (m)	19.01 – 199.5 (m)	0 – 195.5 (m)	Degree of elevation change from cell to cell of DEM
Human Population Density	Continuous	0 – 5709.1 (people/km^2)	0 – 254.5 (people/km^2)	0 – 459.0 (people/km^2)	Density of humans on the block-group scale
Distance to Road	Continuous	0 – 3052.1 (m)	0.1 – 3052.1 (m)	0.2 – 3010.7 (m)	Distance to the nearest road
Sex	Categorical	M – F	M – F	M – F	Male or female
Mixed Hardwood Forest/Regrowth	Categorical	0 – 1	0 – 1	0 – 1	The most common land cover category in the study area. Characterized by forested areas across a variety of hydrologic regimes, with many instances of bottomland soils. Contains a mixture of eastern redcedar, pine species and oak species. Oftentimes successional or a result of a past disturbance.
Moist Oak Forest	Categorical	0 – 1	0 – 1	0 – 1	Closed-canopy forests with hickory species and oak species, with a

					relatively rare occurrence of sugar maple. Common woody understory species include flowering dogwood, eastern redbud, hophornbeam, and sassafras.
Deciduous Woodland	Categorical	0 – 1	0 – 1	0 – 1	Common tree species include oaks, hickories, elms and walnuts. Somewhat similar to Moist Oak Forest, although without the moist landforms and lower levels of insolation
Riparian Forest	Categorical	0 – 1	0 – 1	0 – 1	Narrow, oftentimes steep areas buffering first and second order streams, with high species richness dominated by hardwood species
Pasture/prairie *	Categorical	0 – 1	0 – 1	0 – 1	Open grasslands and pastureland
Anthropogenic	Categorical	0 – 1	0 – 1	0 – 1	Majority human altered land cover types, including urban low/high intensity, barren, row crops, pine plantation. Small minority of rare land cover types that didn't fit in other categories

* reference variable for land cover type selection

Table 3.2 Land cover type reclassification used in resource selection modeling. Forty original classes were reclassified to 6 (Diamond et al. 2014, David Diamond, personal communication), not including open water which was considered unavailable.

Original ID	Original Description	New ID	New Description
14407	Arkansas Valley: Prairie/Pasture	8	Pasture/prairie
9000	Barren	1	Anthropogenic
504	Crosstimbers: Post Oak Forest	3	Deciduous Woodland
503	Crosstimbers: Post Oak - Eastern Red Cedar	2	Mixed Hardwood Forest/Regrowth
506	Crosstimbers: Young Post Oak Woodland	2	Mixed Hardwood Forest/Regrowth
9327	Disturbed Soil Pasture	8	Pasture/prairie
14717	Eastern Great Plains: Herbaceous Wetland	8	Pasture/prairie
9600	Open Water	0	Open Water
2027	Osage Plains: Tallgrass Prairie/Pasture	8	Pasture/prairie
13103	Ozark-Ouachita: Dry Mixed Woodland	2	Mixed Hardwood Forest/Regrowth
13104	Ozark-Ouachita: Dry Oak Woodland	3	Deciduous Woodland
13106	Ozark-Ouachita: Dry Oak Woodland Young Regrowth	2	Mixed Hardwood Forest/Regrowth
13003	Ozark-Ouachita: Dry-Mesic Mixed Forest	2	Mixed Hardwood Forest/Regrowth
13004	Ozark-Ouachita: Dry-Mesic Oak Forest	4	Moist Oak Forest
13006	Ozark-Ouachita: Dry-Mesic Oak Woodland Young Regrowth	2	Mixed Hardwood Forest/Regrowth
9117	Ozark-Ouachita: Pasture/Prairie	8	Pasture/prairie
13500	Ozark-Ouachita: Riparian Barrens	1	Anthropogenic

13506	Ozark-Ouachita: Riparian Deciduous Shrubland	6	Riparian Forest
13515	Ozark-Ouachita: Riparian Evergreen Woodland and Shrubland	6	Riparian Forest
13504	Ozark-Ouachita: Riparian Hardwood Woodland	6	Riparian Forest
13517	Ozark-Ouachita: Riparian Herbaceous Wetland	8	Pasture/prairie
13503	Ozark-Ouachita: Riparian Mixed Woodland	6	Riparian Forest
13403	Ozark-Ouachita: Shortleaf Pine - Oak Forest	2	Mixed Hardwood Forest/Regrowth
9301	Pine Plantation	2	Mixed Hardwood Forest/Regrowth
9307	Row Crops	1	Anthropogenic
9206	Ruderal Deciduous Shrubland and Young Woodland	2	Mixed Hardwood Forest/Regrowth
9104	Ruderal Deciduous Woodland	3	Deciduous Woodland
9103	Ruderal Eastern Redcedar - Mixed Woodland	2	Mixed Hardwood Forest/Regrowth
9115	Ruderal Eastern Redcedar Woodland and Shrubland	2	Mixed Hardwood Forest/Regrowth
14815	South Central Interior: Bottomland Eastern Redcedar Woodland and Shrubland	2	Mixed Hardwood Forest/Regrowth
14804	South Central Interior: Bottomland Hardwood Forest	2	Mixed Hardwood Forest/Regrowth
14817	South Central Interior: Bottomland Herbaceous Wetland	8	Pasture/prairie

14803	South Central Interior: Bottomland Mixed Forest	2	Mixed Hardwood Forest/Regrowth
14806	South Central Interior: Bottomland Shrubland and Young Woodland	2	Mixed Hardwood Forest/Regrowth
14800	South Central Interior: Bottomland Barrens	1	Anthropogenic
15115	South Central Interior: Riparian Eastern Redcedar Woodland and Shrubland	6	Riparian Forest
15104	South Central Interior: Riparian Hardwood Woodland	6	Riparian Forest
14806	South Central Interior: Riparian Shrubland and Young Woodland	6	Riparian Forest
9410	Urban High Intensity	1	Anthropogenic
9411	Urban Low Intensity	1	Anthropogenic

Table 3.3: Top four and null generalized linear mixed resource selection function models at the 2nd order (Johnson 1980) based on Akaike Information Criterion for small samples (AICc, Akaike 1974). Data compared used to available locations from 23 black bears (10M:13F) in the Oklahoma Ozarks. Models with a ΔAICc ≤ 2 were considered competitive (Burnham and Anderson 2002, Simek et al. 2015).

Model	**AIC_c**	**ΔAIC_c[a]**	**ω_i[b]**	**K[c]**
Land Cover + DTR + TRI + Elevation + Human Population Density	16943.9	0.0	0.68	12
Land Cover + DTR + TRI + Elevation + Human Population Density + Sex	16945.4	1.5	0.32	13
Land Cover + DTR + TRI + Human Population Density	17551.6	607.7	< 0.001	11
Land Cover + DTR + TRI + Elevation	17757.8	813.9	< 0.001	11
Null	25407.4	8461.8	< 0.001	3

[a] The difference in AICc between the model listed and the best model
[b] Akaike weight
[c] No. parameters in model

Table 3.4 Beta estimates of all habitat variables within the top model for resource selection on the 2nd order. Selection or avoidance of resource variable was inferred when confidence intervals of fixed effect beta coefficients did not overlap 0.

Variable	**β**	**SE**	**LCL**	**UCL**
Mixed Hardwood Forest/Regrowth *	2.296	0.154	1.994	2.598
Deciduous Woodland*	2.979	0.130	2.725	3.233
Moist Oak Forest*	3.387	0.136	3.121	3.653
Riparian Forest*	3.413	0.148	3.123	3.704
Anthropogenic*	0.986	0.213	0.569	1.403
Elevation	0.586	0.025	0.538	0.634
Terrain Ruggedness Index	0.177	0.027	0.124	0.230
Distance to Road	0.782	0.021	0.741	0.824
Human Population Density	- 0.282	0.010	-0.303	-0.262

* Using land cover type “Pasture/Prairie” as reference variable

Table 3.5 Top four and null generalized linear mixed resource selection function models at the 3rd order (Johnson 1980) based on AICc, for the summer season. Data compared used to available locations from 19 black bears. Models with a ΔAICc ≤ 2 were considered competitive (Burnham and Anderson 2002, Simek et al. 2015).

Model	**AIC_c**	**ΔAIC_c[a]**	**ω_i[b]**	**K[c]**
Land Cover + DTR + Elevation + Human Population Density	18220.7	0.0	0.58	11
Land Cover + DTR + TRI + Elevation + Human Population Density	18222.1	1.4	0.29	12
Land Cover + DTR + TRI + Elevation + Human Population Density + **Sex**	18223.7	3.0	0.13	13
Land Cover + DTR + TRI + Human Population Density	18256.1	35.5	< 0.001	11
Null	19409.5	1188.9	< 0.001	3

[a] The difference in AICc between the model listed and the best model
[b] Akaike weight
[c] No. parameters in model

Table 3.6 Beta estimates of all habitat variables within the top model for resource selection on the 3rd order for the summer season. Selection or avoidance of resource variable was inferred when confidence intervals of fixed effect beta coefficients did not overlap 0.

Variable	**β**	**SE**	**LCL**	**UCL**
Mixed Hardwood Forest/Regrowth*	1.783	0.176	1.437	2.129
Deciduous Woodland*	1.867	0.147	1.580	2.154
Moist Oak Forest*	2.317	0.148	2.027	2.606
Riparian Forest*	2.271	0.164	1.949	2.592
Anthropogenic*	2.027	0.276	1.487	2.568
Elevation	0.136	0.021	0.096	0.176
Distance to Road	0.374	0.019	0.337	0.411
Human Population Density	-0.089	0.010	-0.108	-0.070

* Using land cover type "Pasture/Prairie" as reference variable

Table 3.7 Top four and null generalized linear mixed resource selection function models at the 3rd order (Johnson 1980) based on AICc, for the autumn season. Data compared used to available locations from 22 black bears to an equal number of available locations. Models with a ΔAICc ≤ 2 were considered competitive (Burnham and Anderson 2002, Simek et al. 2015).

Model	**AIC_c**	**ΔAIC_c[a]**	**ω_i[b]**	**K[c]**
Land Cover + DTR + TRI + Human Population Density	15507.5	0.0	1.00	11
Land Cover + DTR + TRI + Elevation	15529.5	22.0	< 0.001	11
Land Cover + DTR + TRI	15532.8	25.3	< 0.001	10
Land Cover + DTR + Human Population Density	15539.6	32.1	< 0.001	10
Null	16596.4	1086.9	< 0.001	3

[a] The difference in AICc between the model listed and the best model
[b] Akaike weight
[c] No. parameters in model

Table 3.8 Beta estimates of all habitat variables within the top model for resource selection on the 3rd order for the autumn season. Selection or avoidance of resource variable was inferred when confidence intervals of fixed effect beta coefficients did not overlap 0.

Variable	**Estimate**	**SE**	**LCL**	**UCL**
Mixed Hardwood Forest/Regrowth *	2.198	0.254	1.699	2.697
Deciduous Woodland*	2.172	0.234	1.714	2.631
Moist Oak Forest*	2.642	0.237	2.178	3.107
Riparian Forest*	3.047	0.244	2.568	3.525
Anthropogenic*	1.603	0.356	0.904	2.301
Terrain Ruggedness Index	0.137	0.023	0.091	0.183
Distance to Road	0.358	0.021	0.317	0.400
Human Population Density	-0.052	0.010	-0.072	-0.031

* Using land cover type “Pasture/Prairie” as reference variable

Figure 3.1: Study area was determined by estimating a 100% minimum convex polygon of all location estimates obtained from radiomarked black bears in the Oklahoma Ozarks region in 2011–2016. Areas of particular interest are labeled, as well as county names and demarcations.

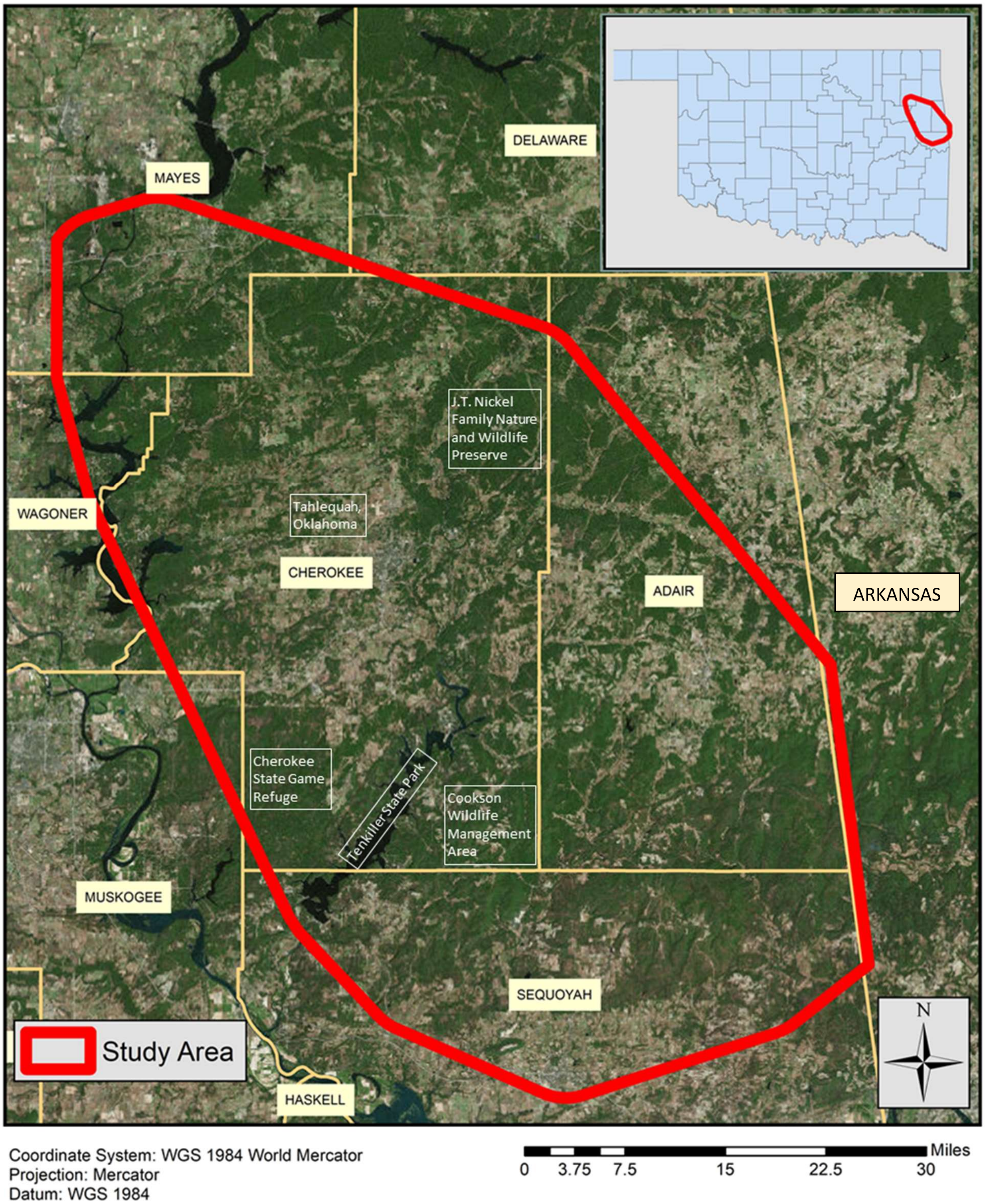


Figure 3.2: Relative probability of use map based on top model 2nd order resource selection function output, confined to the study area. Habitat quality was classified based on probability values in ArcGIS 10.2 as quantiles.

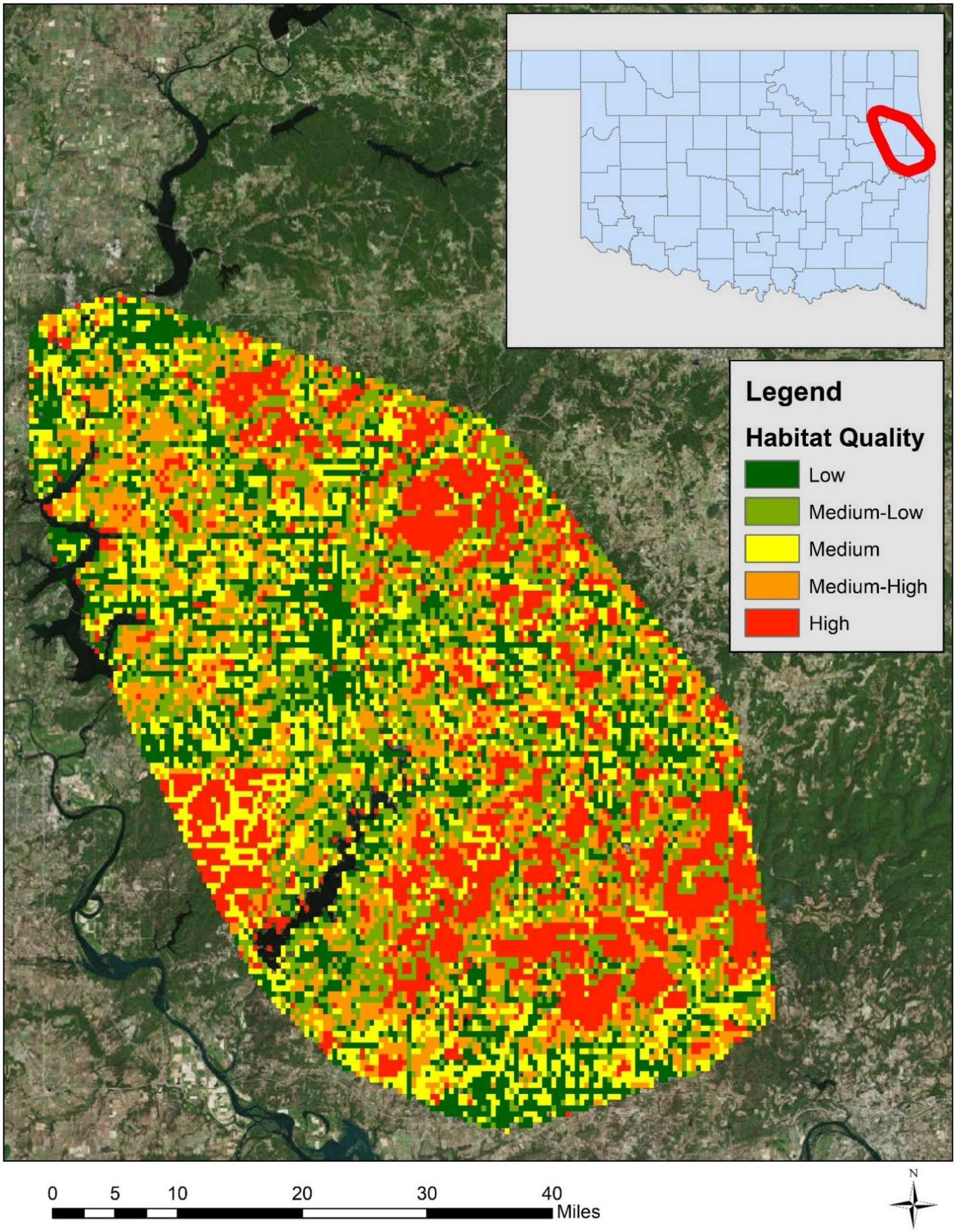
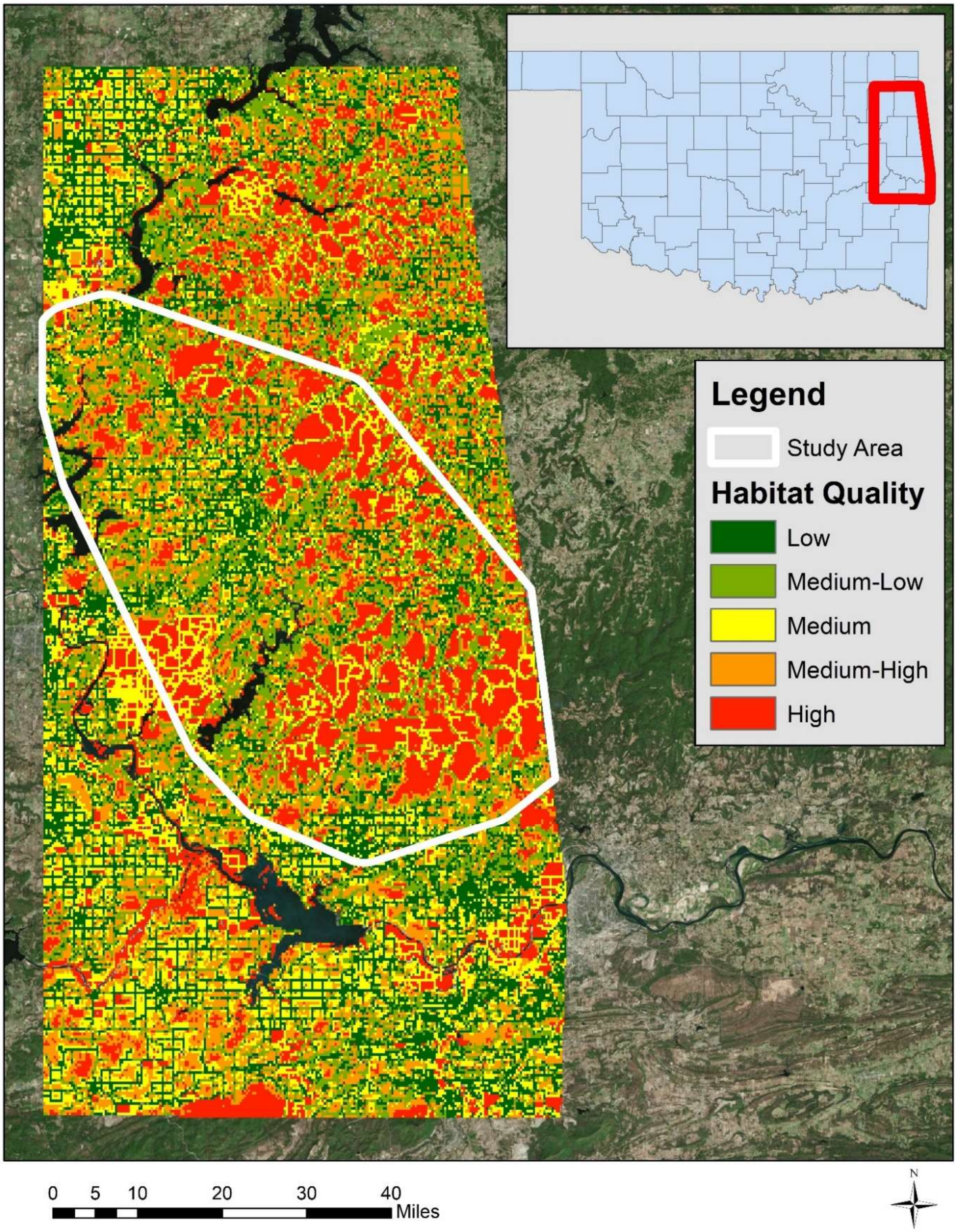


Figure 3.3: Relative probability of use map based on top model 2nd order resource selection function output, extended north and south of the study area along the Arkansas state line. The study area is superimposed for reference. Prediction strength decreases as the model is extended outside of the study area, as variable inputs not included in the original model are introduced.



CHAPTER IV

CONCLUSION

Black bears have successfully recolonized the core area of the Oklahoma Ozarks after being extirpated due to overhunting and habitat loss in the late 19th century (Smith and Clark 1994). This population is somewhat new to the region, having first been detected in the early-2000's (Yaklin 2017). The majority of black bear activity in the region occurs between the border of Oklahoma and Arkansas westward to Cookson Wildlife Management Area in Cherokee and Adair counties. Any evidence that this population is recolonizing outside of the core area is largely limited to data collected from exploratory young males, which are known to venture outside of typical black bear habitat in search of new territory (Pelton 2003). The growth and recolonization of the population is dependent on the female black bears, which have comparatively slow rates of recolonization (Costello 2010, Hiller et al. 2015). Female black bears in the Oklahoma Ozarks are sensitive to human-altered characteristics such as roads, towns and other sources of human activity based on resource selection function output and fragmentation analysis (Chapter II, Chapter III). Naturally low female black bear dispersal rates compounded with resource availability requirements and anthropogenic fragmentation in the study area may be causal to a slower rate of recolonization for the population. However, the combination of favorable management practices and more time could increase the possibility that female black bears will continue to populate the region.

Female black bear 95% isopleth home ranges (summer = 99.4 km^2 ± 44.2, autumn = 75.4 km^2 ± 57.1) were significantly smaller than male 95% isopleth home ranges (summer = 265.6 km^2 ± 153.4, autumn = 171.0 km^2 ± 108.2, p-value for both seasons = 0.002). The relative size differences between sexes is consistent with trends seen in other black bear populations, based on basic black bear ecology and behavior differences (Dahle and Swenson 2003, Pelton 2003). More notably, however, was that the Oklahoma Ozark female seasonal home ranges were significantly larger than female home ranges in the black bear population in the Ouachita Mountains of southeastern Oklahoma (autumn p-value < 0.0001 , spring p-value < 0.0001; Yaklin 2017). A possible explanation is that larger space requirements by female black bears in the Oklahoma Ozarks could be due to a lower degree of habitat suitability across the landscape. This suitability difference is possibly due to lower amounts of resources available, such as food and shelter, a comparatively larger amount of habitat fragmentation in the region (Yaklin 2017), or more likely a combination of both explanations.

Differences in the degree of fragmentation between the Oklahoma Ozark and Ouachita regions may be an important factor when comparing black bear population health and recolonization success (Moyer et al. 2007). Female black bears in the Oklahoma Ozarks were sensitive to fragmentation (Chapter II), caused either by natural processes or human-related activity. Males did not appear to be sensitive to the level of fragmentation in the Oklahoma Ozarks region (Chapter II). Based on home range locations throughout the study area, males exhibited movement through fragmented land whereas females appeared more limited to the core area. Anthropogenic fragmentation in the Oklahoma Ozark region could be a semipermeable barrier to movement through the landscape for females, which may create a sizeable roadblock to further recolonization. Based on both fragmentation and resource selection results, the Oklahoma Ozark region may not be suitable to support similar population numbers to the Ouachita black bear population. However, I believe a more thorough investigation of the two populations' relationship to fragmentation is needed, to more clearly define the differences between populations.

With resource selection function modeling, I determined that both male and female black bears selected strongest for riparian forest and moist oak forest, while selecting weakest for pasture/prairie and anthropogenic land cover types. This behavior is most likely linked to both an avoidance of human activity and a selection for higher amounts of resource availability. Results similar to this are found in multiple studies nationwide (Lyons et al. 2003, Reynolds-Hogland and Mitchell 2007, Sollmann et al. 2016), although examples of different selection patterns can be found in studies where a paucity of natural resources such as food and shelter forces black bears into more human-dominated areas (Johnson et al. 2015). Additionally, black bears selected areas of higher elevation and terrain ruggedness while avoiding human population density and roads. Along with the land cover type selection results, these behaviors further suggested that black bears in the Oklahoma Ozarks are sensitive to human activity. Black bears did not exhibit significant differences in selection by sex. However, when looking solely at the distance to road variable, I found that female black bears avoided roads significantly more than males. This result, combined with comparative home range sizes and sensitivities to fragmentation, leads me to believe that females are more negatively impacted by areas of human activity including roads, urban areas and altered habitats than male black bears.

In a region dominated by humans, such as the Oklahoma Ozarks, there may be impermeable barriers to movement by female black bears from one quality patch to another. Female black bears are the driving force behind population growth (Moyer et al. 2007, Mitchell et al. 2009), and the lack of permeability required by females to move from patch to patch in the Oklahoma Ozarks region could significantly affect the future of this population. If the landscape does not consist of available, high quality patches with enough area to sustain an incoming female (or overlapping females), future recolonization will suffer. Synergizing fragmentation metrics, average home range size calculations and home range overlap indices with resource selection function output could theoretically produce a data-driven spatial representation of the black bear population's status in the region. Future research should address fine-grained movements, especially of female dispersal patterns, to assess willingness of black bears to move across fragmented landscapes to settle in suitable habitat patches. Analysis of utilization distributions could be used to further investigate space use by black bears. Analyzing intraspecific interactions may be important as the recolonization process continues.

Management Implications

Recolonization is a slow process that should be consistently monitored, especially when a human-wildlife interface is involved. My results can direct monitoring the expansion of the population by focusing efforts on areas with high probability of use. Nuisance bears could be translocated to large areas designated as high quality, such as Cherokee State Game Reserve and the J.T. Nickel Family Nature and Wildlife Preserve. If fragmentation proves to be a significant barrier to movement for female black bears, translocations to high quality areas outside of the core area may be essential for the population. Translocated black bears could theoretically spread further, expanding the distribution of the species.

The black bear population in the Oklahoma Ozark region is relatively small in comparison to other black bear populations, with an unbalanced sex ratio of 2.5M:1F (Lyda et al. 2016). Currently, this population of black bears is not being hunted. In other areas, hunting increased the perceived risk of roads by black bears (Stillfried et al. 2015, Hiller et al. 2015), which, in my study area, could further decrease the permeability of anthropogenic fragmentation, thereby potentially hindering further recolonization. If further recolonization by this population is desired, the process could be facilitated by waiting until additional high quality areas have been colonized by female black bears before enacting a hunting season.

Although this study has contributed a better understanding of black bear recolonization in the Oklahoma Ozarks, it is just a first step. Long-term research is essential to more accurately predict this population’s future health and movements. I suggest that additional data collection and monitoring is conducted to create effective management decisions. The role of bait stations or deer feeders on black bear recolonization and behavior is unclear. Based on wildlife sightings and nuisance reports (Sara Lyda, personal communication), black bears are taking advantage of anthropogenic food sources such as deer feeders, potentially due to a low perceived disturbance from humans (Frid and Dill 2002, Sollmann et al. 2016). However, it may be that only a small number of individuals are using those food sources while most of the population relies on natural food sources. Collecting spatial data of anthropogenic food source use either through camera traps, collar spatial data or diet analysis could be important for future management of the population.

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